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PHYSICAL ENVIRONMENT AND FARM HOUSING

An address by J. R. Dodge of the U. S. Bureau of Agricultural Engineering at the annual meeting of the American Society of Agricultural Engineers, St. Paul, Minnesota, Thursday, June 22, 1939

The comfort and health of human beings are dependent on maintaining the body at a fixed temperature. The heat produced by the combustion of food within the body must balance the heat lost from the body, by convection, conduction, radiation and evaporation. Thermal environment determines the rate of heat loss and the manner in which it can be lost. Increase in the temperature of the surrounding air, for example, reduces the amount of heat which can be lost by convection while an increase in the rate of air movement tends to remove more heat from the body in this way. Heat loss due to conduction and radiation is directly affected by the temperature of surfaces and objects which the body touches or to which it is exposed, and the rate of evaporation from the body fluctuates with changes in the relative humidity of the air.

Any change, then, in the conditions to which the body is exposed necessitates adjustment of the bodily mechanisms which regulate internal heat production and heat loss. While the human body is ordinarily quite adaptable, thorough tests have shown that man is comfortable only within a narrow range of thermal conditions. Although a certain amount of variation is desirable within these limits, excessive changes tend to cause discomfort and possibly nervous fatigue.

Regulation of the air and surface temperatures, the rate of air movement and the relative humidity are, therefore, important if the house is to be a comfortable place in which to live.

Developments in heating and air conditioning equipment designed to maintain comfortable house conditions the year around have progressed rapidly. On the other hand, research directed toward improving the structure itself as a factor in comfort has not received much attention.

It is for this reason that the farmhouse comfort projects were established by the Bureau of Agricultural Engineering in cooperation with the University of Wisconsin and the University of Georgia. We worked with Professor R. H. Driftmier and his associates in Georgia and with the late Professor E. R. Jones and members of the staff in Wisconsin. After the death of Professor Jones the University of Wisconsin was represented by Professor F. W. Duffee. As the Wisconsin work progressed Miss May L. Cowles of the Home Economics Department of the University assisted us by arranging for studies of certain features of the farmhouses before and after remodeling. The objects of these investigations were, first, to determine the conditions existing in occupied farmhouses, and the important sources of discomfort, and, second, to develop economical means of improving comfort through good planning, construction, and the proper use of materials and equipment.

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It is for this reason that the [illegible] studies reported were established by the Bureau of Agricultural Engineering in cooperation with the University of Wisconsin and the University of Georgia. In contact with Professor [illegible] and his associates in Georgia and with [illegible] 1934, Professor [illegible] and members of his staff in Wisconsin. After the death of Professor [illegible] the University of Wisconsin was [illegible] by Professor F. W. Duffee. As the Wisconsin work progressed [illegible] the Poultry Husbandry Department of the University [illegible] in conducting the studies of certain features of the [illegible] brooders [illegible]. The objects of these investigations were, first, to determine the conditions existing in [illegible], and the [illegible] of [illegible], second, to [illegible] through [illegible] design, construction, and the proper use of materials and equipment.

A number of different instruments were used in obtaining data. Hygrothermographs kept continuous records of air temperatures and relative humidity. Thermocouples were used in obtaining surface temperatures and were also placed at various heights on portable stands in order to measure variations in air temperature between floors and ceilings in the houses. Mercury thermometers were used in checking readings taken with other instruments. Records of air movement within the houses were obtained with anemometers. In addition to these instruments a pyrheliometer was used on the Georgia project to measure solar radiation.

In Wisconsin all tests were made in 11 occupied farmhouses. Cooperators who planned to remodel or otherwise materially improve their homes were selected in order that the effect of various improvements might be studied. The houses represented a good cross section of farm homes found throughout this region. They ranged in size from 5 to 11 rooms and were from 25 to 75 years old. The condition of the houses also varied. Six had piped warm air systems, one steam heat, one a pipeless furnace and three were heated by stoves. All of the houses were wood frame with the exception of one which was stucco on wood frame.

Winter tests made in the Wisconsin houses prior to remodeling showed that for the most part the houses were decidedly uncomfortable. Air temperatures fluctuated widely throughout the day, changes of from 10 to 20 degrees within a space of two hours being common. At the same time stratification was very great. Temperature differences between the air at the floor and that at the ceiling amounted to as much as 50 degrees

in some cases, and 20-degree differences were quite common. Such variable conditions necessitate continual adjustment of the regulatory mechanism of the body and result in much discomfort.

Wall surface temperatures were generally low enough to cause considerable loss of body heat by radiation. In a number of the houses interior surfaces of outside walls averaged from 10 to 15 degrees less than the temperature of the air in the room. Floors were also very cold. Temperatures as low as 39 degrees were recorded over unexcavated areas.

To compensate for the effect of cold walls and floors and low air temperatures near the floors, the air at the breathing level was generally kept at a very high temperature in most of the houses. As a result, the relative humidity was generally below the recommended minimum and discomfort due to excessive loss of moisture from nose and throat was very noticeable.

While there was considerable infiltration around doors and windows and even through the construction in some of the houses, drafts were very infrequent and in many instances air movement within the houses was less than is generally recommended for comfort. The discomfort caused by this infiltration was apparently due to the temperature of the incoming air rather than its velocity.

The construction and condition of the houses, the type of heating, the kind of fuel used and the irregularity of firing all contributed toward uncomfortable conditions. Studies showed, however, that regardless of other factors, conditions on the whole were better in those

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Wall surface temperatures were generally low enough to cause considerable loss of body heat by radiation. In a number of the houses interior surfaces of outside walls averaged from 10 to 15 degrees less than the temperature of the air in the room. Floors were also very cold. Temperatures as low as 30 degrees were recorded with thermometers resting on floors.

To compensate for the effect of cold walls and floors and low air temperatures near the floors, the air at the breathing level was generally kept at a very high temperature. In most of the houses, as a result, the relative humidity was generally below the recommended minimum and discomfort due to excessive loss of moisture from nose and throat was very noticeable.

While there was considerable infiltration around doors and windows and even through the construction in many of the houses, drafts were very infrequent and in many instances air movement within the rooms was less than is generally recommended for comfort. The discomfort caused by this infiltration was apparently due to the coldness of the incoming air rather than its velocity.

The construction and condition of the houses, the type of heating, the kind of fuel used and the impossibility of having all supplementation tested during severe weather conditions. Heating systems, however, were a combination of other factors, conditions in the homes were varied in these

houses which were tightly constructed, where doors and windows were in good condition, and where there were basements under the entire house.

In summer these houses were generally quite comfortable. The few hot days which are experienced in this section of the country do not appear to warrant the consideration of special construction or means of cooling other than those ordinarily employed.

After preliminary tests were finished, five of the houses were completely remodeled and insulated, one was replaced by a new house, while in another the only improvements were the installation of insulation and the replacement of some of the windows.

All of the work of remodeling was paid for by the owners, but the Bureau furnished complete working drawings and supervision to compensate them for the use of their homes in making these tests. The information resulting from the studies made in the old houses served as a basis for planning the changes. Since it was necessary to complete all of the work of remodeling before making further tests, it was possible to study only the combined effect of all of the changes made in each of the houses.

Conditions in all of the remodeled houses were noticeably improved. Average surface temperatures of walls and floors were increased as much as 17 degrees in some of the houses. The temperatures of the air above the floor were raised from 3 to 20 degrees. The relative humidity was also increased in some cases, especially where some means of adding moisture to the air was provided. Families have also discovered that it is no longer necessary to maintain such high temperatures at the breathing level.

The value of better construction and insulation was clearly shown by the results obtained in the house where the only improvements were insulation and the replacement of some of the poorer windows. In the kitchen, for example, the average temperature of the floor was increased 3 degrees, that of the exterior walls by 17 degrees, and the temperature of the air 3 inches above the floor by 5 degrees.

The living room and the downstairs bedroom which adjoins it have formerly been so hard to heat that they were shut off entirely in winter. Now it is possible to keep all the rooms warm, and to make use of this much needed space.

Because of increases in the size of a number of the houses and changes in the heating systems and type of fuel used, fuel records are not always comparable. However, in one case where the heating plant was not changed and the same type of fuel was being used, a 50 percent saving in fuel was made in spite of the fact that the house is now larger than it was.

These studies have shown that the first steps to be taken toward improving winter comfort in the average farmhouse are to tighten all construction, replace or refit all sash and doors which are in poor condition and insulate the house. It is believed that in many instances new heating systems would be found unnecessary if these suggestions were followed.

Preliminary tests in Georgia were also made in typical occupied farmhouses although more detailed investigations were carried on later in specially constructed test houses.

The five occupied houses studied were all one-story frame houses with the exception of one which was a large 2-1/2 story brick house. The frame houses ranged in size from 3 to 5 rooms and were from 2 to 35 years old. The houses had no basements and were built on piers instead of continuous foundations. Stoves or fireplaces were used in heating all of the houses.

Summer tests made in these houses showed them all to be uncomfortably warm, particularly during the day. Those which were loosely constructed and permitted the passage of air into the stud and attic spaces through walls and roof had somewhat lower air temperatures and felt more comfortable than those which were better built. They also cooled off more rapidly at night.

In the winter the temperatures maintained in these houses were much lower than those recorded in the Wisconsin houses. The average effective temperature in some of these houses was as much as 15 degrees below the minimum recommended for comfort by the American Society of Heating and Ventilating Engineers.

While surface temperatures and stratification were not obtained in these houses, later studies made in test houses of similar construction and with the same type of heating showed that both must constitute sources of considerable discomfort. Observations indicated that these unsatisfactory conditions were probably due to the high rate of infiltration through walls, floors and around doors and windows, to excessive heat loss through walls, floors and ceilings, and to the methods of heating. The relative humidity recorded in these houses, however, was usually satisfactory.

To study more thoroughly the value of various design and construction factors, 6 one-room test houses and two three-room houses were built and investigations continued in them. Each of the one-room houses represented a different type of construction suitable for farm use and each had different thermal characteristics. One house which represented a type of construction common in the South was wood frame with lapped boards on the exterior and finished with beaded ceiling inside. Wood shingles were used on the roof. It had relatively low conductivity but permitted a considerable amount of air to pass into stud and attic spaces through walls and roof due to the loose construction. The heat capacity of this type of construction is low. The second had a wood frame with sheet metal side walls and roof and the inside was finished with metal. This house had very little air movement through the construction. Although the walls and roof had a high conductivity, the heat capacity was very low.

The third also had a wood frame with solid sheathing on both the exterior and interior of the walls. The outside was covered with sheet metal, and the roof was also metal on solid sheathing. This house had some of the characteristics of each of the two previous houses. It had relatively low conductivity and heat capacity and permitted practically no air to pass into the construction through walls or roof. The fourth and fifth houses both had walls with high conductivity and fairly high heat capacity. No infiltration was possible through the walls of either. One of these had walls constructed of pre-cast concrete panels exposed on the inside. The roof was composition shingle on solid sheathing. The walls of the other were stucco on metal lath back plastered to form an interior finish. This house was the only one having a flat roof. This roof was insulated with 6 inches of treated cottonseed hulls to compensate for lack of an attic air space.

The sixth house had a steel frame with 4-inch brick veneer on the exterior. It was sheathed with 1/2 inch insulating board, and the interior was plastered. The walls of this house had low conductivity, but the heat capacity was high. There was no air movement through walls or roof. The type of construction used in this last house, while very satisfactory, is somewhat expensive for farm use.

The three-room houses were of ordinary frame construction and rested on piers. The walls were of removable and interchangeable panels in order that ceiling heights, door and window locations and wall construction could be varied.

In summer when all the doors and windows were open it was found that the average inside air temperatures over a twenty-four-hour period were within one degree of being the same in all houses regardless of the type of construction. For a short time during the hottest part of the day a maximum difference of 4 1/2 degrees was recorded.

The feeling of comfort experienced in the various houses differed greatly, even when the air temperatures were the same. This was due to the great differences in wall and ceiling temperatures, which, in all of the houses, were high enough during the greater part of the day to radiate some heat to the body. Surface temperatures were as much as 10 degrees higher in those with walls and roofs which were good conductors and where there was little or no air movement in the construction. Since the exchange of heat by radiation between surfaces varies directly as the difference between the temperatures of the two surfaces raised to the fourth power it can be seen that the amount of heat received by the body in this manner would be <u>considerably</u> greater in those houses with high surface temperatures.

Four inches of cottonseed hulls were then placed in the ceilings of all the houses. This had the effect of lowering air and surface temperatures somewhat in the houses with tight construction. On the other hand, in those with loose construction little improvement was observed, save for a slight reduction in the temperature of the ceiling during the hottest part of the day.

The use of insulation in both walls and ceiling of one of the tightly constructed houses resulted in lower average air and surface temperatures than those found in loosely constructed houses, although the maximums reached during the day were slightly higher.

In addition to these tests, studies were also made of some of the more common practices designed to increase summer comfort. Gable ventilators or louvers of the sizes ordinarily found in houses had no apparent effect on inside temperatures, although when used with open cornices a slight improvement was noted.

Tests made in the houses with loose construction showed that ceiling heights of 10 feet were apparently no more effective than those of 8 feet. High ceilings increase the case of construction somewhat, and the amount of air and wall surface to be treated in winter is also greater.

Tests made in the winter in the one-room houses revealed that the houses with high infiltration and those with walls and ceilings having high conductivity were by far the most uncomfortable. Those with high conductivity, which were tightly constructed, had somewhat lower surface temperatures but required slightly less fuel to maintain a given air temperature than those which were loosely built. Apparently, the reason is that infiltration through the walls in cold weather not only cools interior surfaces but, in addition, introduces considerable cold air directly into the room. The two houses which had walls with low conductivity and were tightly constructed were quite comfortable.

Ceiling insulation was again installed in these houses and once more all of the tightly constructed houses showed improvement while the houses with high infiltration were not noticeably benefited.

More complete tests of the effects of infiltration were made in the two three-room houses. One of these houses was caulked to approximate the effect of building paper and weather stripping while the other remained unchanged. Fuel savings of from 15 percent to 45 percent were recorded in the caulked house with outside wind velocities of from 4 to 8 miles per hour. It is probable that there would be even greater savings with a higher wind velocity.

Curtain walls or continuous foundations in place of piers resulted in an additional saving in fuel of 30 percent. Ceiling insulation installed in the house without caulking or curtain walls reduced fuel consumption only 15 percent.

These tests clearly show the value of tight construction, curtain walls, and insulation for winter comfort. On the other hand, no satisfactory means of improving conditions in the summer has yet been developed to a practical stage, although it is evident that discomfort is largely due to radiation from hot walls and ceilings. Mechanical cooling would, of course, be effective, but it is improbable that it will be within reach of the average Southern farmer, even if the cost of equipment is radically reduced.

The insulation of walls and ceilings is also valuable in reducing air and surface temperatures during the day. It tends to retard the loss

of heat at night, however, and adequate ventilation is necessary if it is to be employed. Such complete insulation is also too expensive for many farm families.

Further studies are, therefore, being made in an effort to find economical methods of increasing air circulation through stud and attic spaces during hot weather. Ventilators at the top and bottom of walls, which can be shut off in winter, are to be tested. Ridge- and cupola-type ventilators, larger gable ventilators and exhaust fans are being studied to provide better means of attic ventilation.

Preliminary tests of desert coolers f r reducing inside temperatures have been made, and the possibility of covering flat-roofed houses with water is also being considered.

While trees and shrubbery have always been used as protection from solar radiation, their full value may not be realized. It is believed that due to evaporation their leaves are generally cooler than the surrounding air and as a result, they may also serve to remove heat by radiation from the houses which they shade. While no tests have been made, observations indicate that vines on trellises used as screens do not cut off air circulation from windows and doors, and are quite effective in cooling the walls of a house.

Since a considerable amount of heat enters the house as a result of direct solar radiation through windows and doors, awnings, shutters, venetian blinds and even shades are important in reducing inside temperatures. Porches and overhanging eaves are also effective for this purpose, and their relative values are being studied.

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Preliminary tests of desert coolers for reducing inside temperatures have been made, and the possibility of providing flat-roofed houses with attics is also being considered.

While trees and shrubbery have always been used as protection from solar radiation, their full value may not be realized. It is believed that since through evaporation their leaves are generally cooler than the surrounding air and, as a result, they may also serve to remove heat by radiation from the persons within their shade. While no experiments have been made, observation indicates that trees, shrubbery and vines as screens to cut off sky radiation from windows and doors, and are quite effective in cooling the walls of a house.

Although considerable amounts of heat enters the house as a result of direct solar radiation through windows and doors, awnings, shutters, venetian blinds and even plants are important in reducing inside temperatures. Porches and overhanging eaves are also effective for this purpose, and their relative values are being studied.